

Statistical Studies of the Inhibition Characteristics of Acidified Ocimum Basilicum on Engineering Mild Steel

Michael O. Nwankwo¹, Paul A. Nwobasi², Simeon I. Neife³, Ndubuisi E. Idenyi¹.

¹ Department of Industrial Physics, Ebonyi State University

² Department of Technology and Vocational Education, Ebonyi State University

³ Department of Metallurgical and Materials Engineering, University of Nigeria

^{1,2} Abakaliki, Nigeria; ³Nsukka.

michaelnwankwo@yahoo.com; awonwobasi@yahoo.com; drneifes@gmail.com; edennaidenyi@yahoo.com

Abstract

A study of the correlation behavior of the inhibition characteristics of acidified ocimum basilicum on conventional engineering mild steel has been undertaken. Weight-loss corrosion technique was employed to obtain the corrosion penetration rate using the equation: $cpr = \frac{87.6\Delta w}{\rho At}$.

Subsequently, the quadratic models were developed using a computer-aided statistical modeling technique (International Business Machine (IBM)'s SPSS version 17.0). The results obtained showed a nearly perfect positive correlation with a correlation coefficient in the range of $0.986 \leq R \leq 0.996$, which depicts that R is larger than 1. Also, the coefficient of determination is in the range of $0.972 \leq R^2 \leq 0.992$ showing that approximately 97% to 99% of the total variation in passivation rate is accounted for by corresponding variation in exposure time, leaving out only between 3% to 1% to extraneous factors that are not incorporated into the model equations. The conclusion drawn from this observation is that the model fit developed from the model equations is accurate and will be a good predictor of the passivation behaviour of mild steel in acidified ocimum basilicum; and that room temperature behavior of corrosion progression can no longer be only logarithmic but now has non-negligible quadratic parts. This is a classical departure from long-held assumptions that corrosion behaviours are only somewhat logarithmic at room temperatures.

Keywords

Corrosion; Inhibition; Ocimum Basilicum; Correlation; Quadratic Models; Passivation

Introduction

Corrosion can be defined as the environmentally induced degradation of a material that involves a chemical reaction (Duquette et al., 2011). Degradation implies deterioration of physical properties of the material. This can be a weakening of the material due to a loss of cross-sectional area, the shattering of a

metal due to hydrogen embrittlement, or the cracking of a polymer due to sunlight exposure.

Most authors insist that the definition of corrosion should be restricted to metals, but more often than not, corrosion engineers must consider both metals and nonmetals for solution of a given problem. Accordingly, polymers (plastics, rubbers, etc.), ceramics (concrete, brick, etc.) or composites (mechanical mixtures of two or more materials with different properties) and other nonmetallic materials are generally included as materials that can corrode (Fontana, 2005).

Some of the deleterious effects of corrosion are known to include among others poor outward appearance of material surfaces, high maintenance and operating costs, frequent plant shutdowns, contamination of end products, loss of valuable products, hazardous effects on safety and reliability and burdensome product liabilities. Consequent upon these, huge financial losses have always been recorded as resulting from corrosion damage. For instance, estimates of the annual cost of corrosion in the United States alone are said to be around \$276 billion but realistically put at \$30 billion as at 1998 (Fontana, 2005). By March 2013, it was evaluated to be \$993 billion with a projected figure of \$1 trillion by June 2013 (G2MT Lab., 2011).

Even with the proper selection of base metals and well-designed systems or structures, there is no absolute way to eliminate all corrosion. Therefore, corrosion protection methods are used to additionally mitigate and control the effects of corrosion. Corrosion protection can be in a number of different forms or strategies with perhaps multiple methods applied in severe environments. (Craig, Lane & Rose, 2006). The various forms of corrosion protection include among others the use of inhibitors, surface treatments,

coatings and sealants, cathodic protection and anodic protection.

With such staggering financial loss values earlier stated, the need to find cost-effective and environmentally-friendly corrosion control measures becomes dire. In this respect, the use of natural plants as corrosion inhibitors has in recent times become the centrifuge of most research activities. Inhibitors themselves are chemicals that react with the surface of a material decreasing the material's corrosion rate, or interact with the operating environment to reduce its corrosivity. They can be added into the corrosion medium as solutions or dispersions to form a protective film, or as additives in coating products, or further still into waters used for washing vehicle, system or component. When added, they interact with the metal, thus slowing the corrosion process by shifting the corrosion potential of the metal's surface toward either the cathodic or anodic end; preventing permeation of ions into the metal; or increasing the electrical resistance of the surface (Craig et al, 2006).

In Africa, and particularly Nigeria, a vast number of natural plants are continuously been investigated as profitable alternatives to synthetic inhibitors because of their obvious advantages which include among other things, their ready availability, biodegradability, non-toxicity, non-pollutancy and eco-friendliness (Boxer and Back, 1980; Duke, 1985). These formed the choice of *ocimum basilicum* for this work.

Ocimum basilicum, a vegetable plant whose origin is believed to be Indian (Kumpawat, Chaturvedi & Upadhyay, 2012; Muesnscher and Rice, 1978; Stobert, 1982), belongs to a popular plant species called basil. There are several varieties of basil in existence, some of which have been used in previous works (Ashassi-Sorkhabi, Shabani, Aligholipour & Seifzadeh, 2006; Abiola, Okafor, Ebenso & Nwinuka, 2007; Kumpawat, Chaturvedi & Upadhyay, 2010; Soule, 2011). However, *basilicum* species has not been investigated previously in relation to mild steel to the best of the authors' knowledge.

The use of statistical tools (particularly regression analysis) in corrosion studies is a novel approach that could be credited to Ekuma and Idenyi (2007). From thence further works have been done to develop models to predict the corrosion behavior of engineering materials using specific parameters (Ekuma, Idenyi & Owate, 2010; Nwoye, Idenyi & Odo, 2012). The findings from these works show that corrosion profiles correlated better in the quadratic models than the

logarithmic models at room temperatures. This is expected judging from the fact that practically, passivation phenomena follows somewhat a parabolic fashion whereby the corrosion proceeds rapidly at the initial stages, peaking at a maximum when the entire metal surface has been fully shielded from the medium. Thereafter, the corrosion progression slows down. So this work is primarily an attempt to establish the applicability of *ocimum basilicum* as a potent corrosion inhibitor and also to reinforce the findings of Ekuma and Idenyi with regards to the regression behavior of corrosion rates at room temperatures.

Experimental Techniques

Materials/Equipment

The materials and equipment used for the work include 10 mm diameter mild steel rods sourced from a local steel stockiest in Enugu, Nigeria, beakers, digital weighing balance, tetraoxosulphate (VI) acid, leaves of *ocimum basilicum*, acetone, nylon strings, emery cloth, distilled water, hacksaw, vernier caliper, measuring cylinder, and volumetric flask.

Materials Preparation

The mild steel rods were cut to sizes, each averaging 94.5 cm² in surface area. They were thoroughly brushed with emery cloth to reveal the metal surface. Thereafter, they were washed with distilled water and rinsed with acetone.

The tetraoxosulphate (VI) acid was prepared to 0.5 M and 1.0 M concentrations using standard procedures.

The *ocimum basilicum* leaves were washed with cold tap water, dried under room temperature after which they were subjected to soxhlet extraction process in ethanol for about 80 hours to obtain the extract.

Experimentation

The mild steel coupons were tied with nylon strings and then suspended in beakers containing the acid and the acidified extracts. Each beaker contained 5 coupons and the entire set up was allowed to stand for 30 days. After 6 days, a coupon was withdrawn from each beaker, rinsed in distilled water and swabbed in acetone. Thereafter they were weighed for weight loss determination and corrosion rate calculation using the formula:

$$cpr = \frac{87.6\Delta w}{\rho At}$$

The pH value of the *ocimum basilicum* extract was evaluated and noted.

Results

Tables 1–6 show the corrosion penetration rate values obtained from weight loss measurements; while Figures 1–6 are the quadratic model fits from regression analysis of the corrosion penetration rates. Table 8 is the quadratic model equations obtained from the regression analysis.

TABLE 1 CORROSION PENETRATION RATES OF MILD STEEL SAMPLE IN 0.5M H₂SO₄

Exposure time (hrs)	Initial weight (g)	Final weight (g)	Weight loss (g)	Corrosion rate (mm/yr)
144	26.76	20.46	6.30	0.5178
288	26.34	19.59	6.75	0.2774
432	26.87	19.77	7.10	0.1945
576	26.51	19.00	7.51	0.1543
720	27.01	15.93	11.11	0.1826

TABLE 2 CORROSION PENETRATION RATES OF MILD STEEL SAMPLE IN 0.5M H₂SO₄ WITH 25cm³ OF OCIMUM BASILICUM

Exposure time (hrs)	Initial weight (g)	Final weight (g)	Weight loss (g)	Corrosion rate (mm/yr)
144	25.14	19.04	6.10	0.5013
288	28.82	22.29	6.53	0.2683
432	28.36	21.80	6.56	0.1767
576	27.61	20.67	6.94	0.1422
720	26.90	17.80	9.10	0.1596

TABLE 3 CORROSION PENETRATION RATES OF MILD STEEL SAMPLE IN 0.5M H₂SO₄ WITH 50cm³ OF OCIMUM BASILICUM

Exposure time (hrs)	Initial weight (g)	Final weight (g)	Weight loss (g)	Corrosion rate (mm/yr)
144	28.02	22.46	5.56	0.4560
288	27.24	21.05	6.19	0.2544
432	27.93	21.63	6.30	0.1745
576	27.41	20.36	7.08	0.1444
720	27.38	17.38	10.00	0.1454

TABLE 4 CORROSION PENETRATION RATES OF MILD STEEL SAMPLE IN 1.0M H₂SO₄

Exposure time (hrs)	Initial weight (g)	Final weight (g)	Weight loss (g)	Corrosion rate (mm/yr)
144	25.70	14.84	10.86	0.8926
288	25.64	12.69	12.95	0.5322
432	25.50	12.35	13.15	0.3603
576	24.47	9.82	14.65	0.2900
720	26.63	10.63	16.00	0.2630

TABLE 5 CORROSION PENETRATION RATES OF MILD STEEL SAMPLE IN 1.0M H₂SO₄ WITH 25cm³ OF OCIMUM BASILICUM

Exposure time (hrs)	Initial weight (g)	Final weight (g)	Weight loss (g)	Corrosion rate (mm/yr)
144	26.58	17.03	9.55	0.7849
288	26.40	16.36	10.04	0.4126
432	26.81	15.53	11.28	0.3090
576	24.80	12.69	12.11	0.2488
720	25.10	6.08	17.02	0.2305

TABLE 6 CORROSION PENETRATION RATES OF MILD STEEL SAMPLE IN 1.0M H₂SO₄ WITH 50cm³ OF OCIMUM BASILICUM

Exposure time (hrs)	Initial weight (g)	Final weight (g)	Weight loss (g)	Corrosion rate (mm/yr)
144	27.71	18.42	9.29	0.7635
288	27.22	16.85	10.37	0.4261
432	26.86	15.29	11.57	0.3170
576	25.19	12.97	12.22	0.2318
720	24.73	10.63	14.10	0.2511

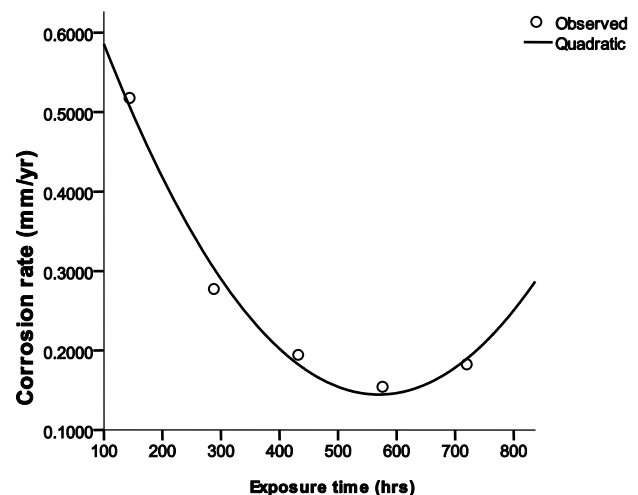


FIG. 1 QUADRATIC MODEL FIT FOR 0.5M H₂SO₄ ONLY.

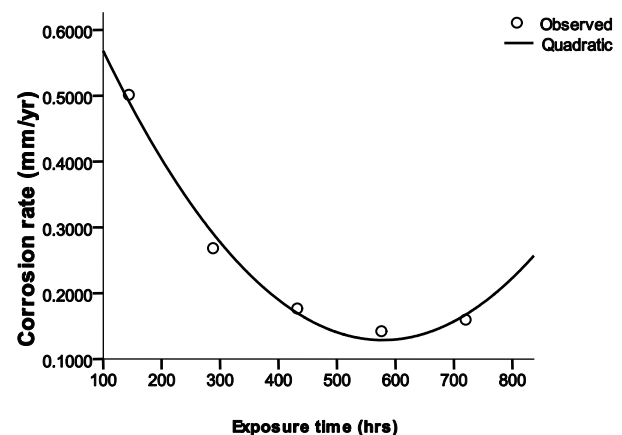


FIG.2 QUADRATIC MODEL FIT FOR 0.5M H₂SO₄ WITH 25cm³ OCIMUM BASILICUM.

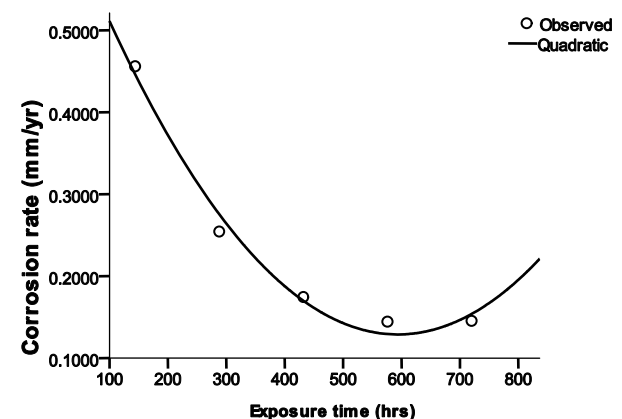
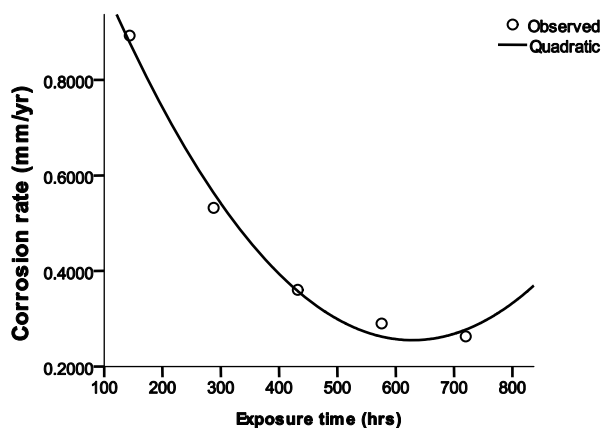
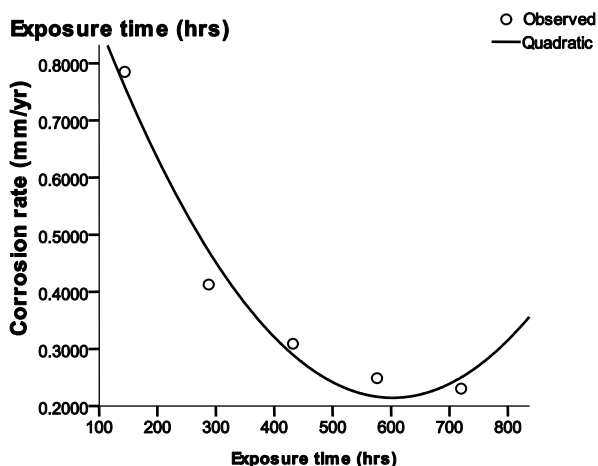
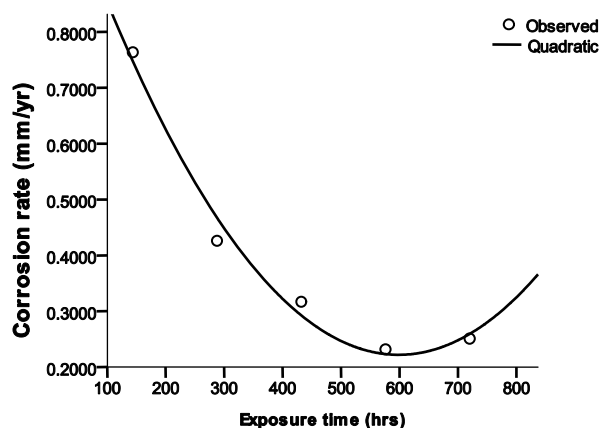


FIG. 3 QUADRATIC MODEL FIT FOR 0.5M H₂SO₄ WITH 50cm³ OCIMUM BASILICUM.

FIG. 4 QUADRATIC MODEL FIT FOR 1.0M H₂SO₄ ONLYFIG.5 QUADRATIC MODEL FIT FOR 1.0M H₂SO₄ WITH 25cm³ OCIMUM BASILICUM.FIG. 6 QUADRATIC MODEL FIT FOR 1.0M H₂SO₄ WITH 50cm³ OCIMUM BASILICUM.

Discussion

A cursory look at the tables shows that the corrosion rates obtained were typical of those of passivating metals. This is usually associated with an initial steep rise in corrosion rate, then peaking at a maximum and subsequently decreasing as exposure time increased. The metal surface on interaction with the corrosion medium normally reacts swiftly with the medium forming an oxide that coats the entire surface and acts a barrier, thereby preventing further reactions (Callister, 1997).

Molar Concentration of Acids

The corrosion rates during the first six days were above the acceptable maximum (put at 0.5 mm/yr for most metals) in the entire media (although in varying proportions) except for 50 cm³ of extract in 0.5 M H₂SO₄. From the next six days up to the 30th day, the rates fell below the minimum in all but 1.0 M H₂SO₄ where the second six days recorded 0.53222 mm/yr. What this implies is that the molarity of the acid had a significant effect on the corrosion rate, in agreement with previous works (Oguzie, Onuchukwu & Ebenso, 2006; Oguzie, 2006).

On the whole, the values obtained for the two molar concentrations of the acid showed that at higher molarities, the corrosion rates were higher comparatively, and although most of the corrosion penetration rate values fell below the permissible limits, and the trend indicated a decrease in corrosion rate as exposure time increased.

Volumetric Concentrations of the Extract

In a similar fashion, the corrosion penetration rates decreased as the volume of the extract increased. This shows that ocimum basilicum is a good inhibitor. The inhibition effects however varied with the concentration of the acid such that corrosion rate values were higher at higher acid concentrations notwithstanding the fact that more extract volume was used. This is without prejudice to the fact that the values were still below the required maximum penetration rate of 0.5 mm/yr.

TABLE 7 MODEL EQUATIONS OF THE VARIOUS QUADRATIC FITS

Corrosion medium	Model equations
0.5M H ₂ SO ₄ only	$0.793 - 0.002t + 1.998 \times 10^{-6}t^2$
0.5M H ₂ SO ₄ + 25cm ³ ocimum basilicum	$0.771 - 0.002t + 1.922 \times 10^{-6}t^2$
0.5M H ₂ SO ₄ + 50cm ³ ocimum basilicum	$0.682 - 0.002t + 1.567 \times 10^{-6}t^2$
1.0M H ₂ SO ₄ only	$1.302 - 0.003t + 2.647 \times 10^{-6}t^2$
1.0M H ₂ SO ₄ + 25cm ³ ocimum basilicum	$1.155 - 0.003t + 2.588 \times 10^{-6}t^2$
1.0M H ₂ SO ₄ + 50cm ³ ocimum basilicum	$1.132 - 0.003t + 2.540 \times 10^{-6}t^2$

TABLE 8 MODEL PARAMETERS

Corrosion Medium	Parameters			
	R	R ²	Adjusted R ²	Standard Error of Estimation
0.5M H ₂ SO ₄	0.994	0.988	0.976	0.023
0.5M H ₂ SO ₄ + 25cm ³ Ocimum basilicum	0.995	0.990	0.980	0.021
0.5M H ₂ SO ₄ + 50cm ³ Ocimum basilicum	0.994	0.988	0.975	0.021
1.0M H ₂ SO ₄	0.996	0.992	0.984	0.033
1.0M H ₂ SO ₄ + 25cm ³ Ocimum basilicum	0.986	0.972	0.944	0.054
1.0M H ₂ SO ₄ + 50cm ³ Ocimum basilicum	0.993	0.986	0.972	0.037

Model Summary

From Table 8, it can be seen that R (coefficient of correlation) values ranged from 0.986 to 0.996 showing that R is larger than 1, which is a near-perfect correlation; while the R^2 (coefficient of determination) values ranged from 0.972 to 0.992, implying that approximately between 97% to 99% of the entire variation in passivation rate is dependent on exposure time, leaving only a maximum of 3% to extraneous sources such as errors of measurements, experimental procedures and test locations.

Also, the standard error of estimation fell between 0.021–0.054 which is significantly less than 0.1. The implication of this very narrow error margin is that the use of quadratic models to characterize corrosion rates at room temperature is justifiable and therefore it could be employed. That being the case, a classical departure from the long-held assumptions that corrosion rate behaviours are only logarithmic at room temperatures has been established.

These claims are corroborated by the patterns of figures 1–6 where the lines of best fits agree with the near perfectness of the correlation data obtained.

Model Equations

From Table 7, the model fit equations show that each has a non-negligible quadratic element that must be accounted for during corrosion rate evaluation. Since time and media are critical considerations in corrosion monitoring, for a given medium therefore the exposure time becomes the overriding factor for corrosion progression, hence our time-dependent quadratic models subsist in this present study.

Furthermore, looking at the equations in the order in which they appeared, both the constant term and the coefficient of t^2 decreased as the volume of the extracts increased in each of the acid molarities. This confirmed further that inhibition has taken place and that an increase in the inhibitor concentration caused a decrease in corrosion penetration rate.

Conclusion

Based on the foregoing discussions, it is concluded that ocimum basilicum is a good corrosion inhibitor which could cause passivation, since its pH value falls within the region in which passivation occurs in the Pourbaix diagram (Ijomah, 2001). Again the quadratic model fits showing a nearly perfect correlation suggests very strongly that corrosion progression can no longer be said to be only logarithmic at room temperature but do have a non-negligible quadratic part that must be accounted for during corrosion characterizations.

ACKNOWLEDGEMENT

The authors wish to acknowledge the Department of Industrial Chemistry of Ebonyi State University for granting them the permission to use their facilities for the work.

REFERENCES

- Abiola, O. K., Okafor, N. C., Ebenso, E. E. & Nwinuka, N. M. (2007). Ecofriendly corrosion inhibitors: The inhibitive actions of delonix regia extract for corrosion of aluminum in acidic media. *Anticorrosion Methods and Materials*, 54 (4) 219 – 224.
- Ashassi-Sorkhabi, H., Shabani, B., Aligholipour, B. & Seifzadeh, D. (2006). The effect of some Schiff bases on the corrosion of aluminum in hydrochloric acid solution. *Applied Surface Sciences*, 252 (12) 4039 – 4047.
- Boxer, A. & Back, P. (1980). *The herb book*. London: Octopus Books Ltd.
- Craig, B. D., Lane, R. A. & Rose, D. H. (2006). *Corrosion prevention and control: A program management guide for selecting materials*. New York: Alion Science and Technology.
- Duke, J. A. (1985). *Culinary herbs: A potpourri*. New York: Bouch Magazine Ltd.

- Duquette, D. J. & Schafrik, R. E. (Co-Chairs)(2011). *Research opportunities in corrosion science and engineering*. Washington DC: National Academy of Sciences.
- Ekuma, C. E. & Idenyi, N. E. (2007). Statistical analysis of the influence of environment on prediction of corrosion from its parameters. *Research Journal of Physics, USA*, 1 (1) 27 – 34.
- Ekuma, C. E., Idenyi, N. E. & Owate, I. O. (2010). Application of statistical technique to the analysis of passivation of Al – Zn alloy systems in brine. *Journal of Chemical Engineering and Materials Science, USA*, 1 (1) 1 – 7.
- Fontana, M. G. (2005). *Corrosion engineering*. New Delhi: Tata McGraw-Hill Publishing Company Ltd.
- Ijomah, M. C. N. (1991). *Elements of corrosion and protection theory*. Enugu: Auto-Century Publishing Company Ltd.
- Kumpawat, N., Chaturvedi, A. & Upadhyay, R. K. (2010). Comparative study of corrosion inhibition efficiency of stem and leaves extract of ocimum sanctum (holy basil) for mild steel in HCl solution. *Protection of Metals and Physical Chemistry of Surfaces*, 46 (2) 267 – 270.
- Kumpawat, N., Chaturvedi, A. & Upadhyay, R. K. (2012). Comparative study of corrosion inhibition efficiency of naturally occurring ecofriendly varieties of holy basil (tulsi) for tin in HNO₃ solution. *Open Journal of Metals, USA*, 2 68 – 73.
- Muenschner, W. C. & Rice, M. A. (1978). *Garden spice and wild pot-herbs*. New York: Cornell University Press.
- Nwoye, C. I., Idenyi, N. E. & Odo, J. U. (2012). Predictability of corrosion rates of aluminum-manganese alloys based on initial weights and exposure time in atmosphere. *Nigerian Journal of Materials Science and Engineering*, 3 (1) 8 – 14.
- Oguzie, E. E. (2006). Studies on the inhibitive effects of ocimum viridis extracts on the acid corrosion of mild steel. *Materials Chemistry and Physics*, 99 (2-3), 441 – 445.
- Oguzie, E. E., Onuchukwu, P. C., & Ebenso, E. E. (2006). Corrosion inhibition and adsorption behaviour of ocimum basilicum extracts on aluminum. *Pigment and Resin Technology*, 35 (2), 63 – 70.
- Soule, J. A. (2011). *Father kino's herbs: Growing and using them*. Arizona: Tierra del sol Institute Press.
- Stobart, T. (1982). *Herbs, spices and flavorings*. New York: The Overbook Press.